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CT IMAGING OF AN EGYPTIAN MUMMY

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1. Introduction

Over the last few years various research groups around the world have employed X-ray Computed Tomography (CT) imaging in the study of mummies – Toronto-Boston [1,2], Manchester[3]. Prior to the development of CT scanners, plane X-rays were used in the investigation of mummies. Xeroradiography has also been employed[4]. In a xeroradiograph, objects of similar X-ray density (very difficult to see on a conventional X-ray) appear edge-enhanced and so are seen much more clearly.

CT scanners became available in the early 1970s. A CT scanner produces cross-sectional X-rays of objects. On a conventional X-radiograph individual structures are often very difficult to see because all the structures lying in the path of the X-ray beam are superimposed, a problem that does not occur with CT. Another advantage of CT is that the information in a series of consecutive images may be combined to produce a three-dimensional reconstruction of an object. Slices of different thickness and magnification may be chosen.

Why CT a mummy? Prior to the availability of CT scanners, the only way of finding out about the inside of a mummy in any detail was to unwrap and dissect it. This has been done by various research groups – most notably the Manchester, UK and Pennsylvania University, USA mummy projects[5,6]. Unwrapping a mummy and carrying out an autopsy is obviously very destructive.

CT studies hold the possibility of producing a lot more information than is possible from plain X-rays and are able to show the *undisturbed* arrangement of the wrapped body. CT is also able to provide information about the internal structure of bones, organ packs, etc that wouldn't be possible without sawing through the bones etc. The mummy we have scanned is encased in a coffin which would have to have been broken open in order to remove the body (Figure 1).

At St. Thomas' Hospital (STH) we have produced a complete series of scans of *Tjentmutengebtiu* (which from now on will be abbreviated to *Jeni*) an Egyptian priestess from the 21st dynasty (1085-945 BC). The art of embalming peaked during the 21st dynasty and Jeni was chosen by the curators of the British Museum (BM) as representative of this period. Jeni is encased in a beautifully decorated anthropoid coffin made of cartonage (a mixture of linen and plaster).

Jeni was brought over from the BM to STH (about 2 miles) on five occasions – always in the evening when the scanner (Siemens DRH) was no longer being used for patients. The mummy was transported in a padded wooden packing case to STH. Curators from the BM came over with the mummy and took it back the same evening after each scanning session.

On the first occasion the head and neck were scanned with a slice thickness of 2 mm and a magnification factor of 2. The slice thickness is the width of the X-ray beam used to produce the image and the magnification factor dictates the size that objects appear in the image; e.g. – an image taken with a magnification factor of 2 has 2 pixels per mm. (Pixel is short for *picture element*).

Over the next three sessions, the rest of the body was scanned using a slice thickness of 4 mm and a magnification factor of 2. On the fifth and final session, the teeth were scanned in high resolution with a slice thickness of 1 mm and a magnification factor of 3.7. During the fourth session, bone mineral measurements were also made, and a collection of amulets were scanned to enable cross comparison with the objects seen within the mummy.

The CT images (about 600 in all) were stored on magnetic tape and then transferred onto a Titan graphics-supercomputer (Kubota Pacific Computer Inc, Santa Clara, CA). A suite of programs has been developed at STH for producing 3D reconstructions from a series of 2D images. These programs are used for planning neurosurgical and orthopaedic operations.

The programs enable the CT images to be manipulated in various ways. For instance image contrast may be adjusted to enable different features of an image to be seen more clearly. This is possible as because the images are stored in digital form, i.e. as a series of numbers. Each CT image is composed of a block of 512 × 512 numbers. Each number represents the X-ray density of the material in the object being scanned. Bone absorbs X-rays more readily than, for example, linen and therefore is represented by bigger numbers in a CT image.

In any particular image there may well be a very large variation in CT number – high numbers for bone, low numbers for linen. This makes bone and linen difficult to see on the same image. To overcome this problem, only a certain range of CT numbers may be selected for display – these are displayed using the full contrast range of the display monitor. This technique is known as *windowing*. If a linen window is chosen, bone becomes whited out, and, if a bone window is chosen linen will hardly be visible.

Another program enables information from a parallel sequence of CT images to be used to produce a 3D reconstruction of objects. This is done by a surface finding algorithm which exams the data in order to extract surfaces of a certain CT number. For instance, in order to

produce a 3D image of the bone (as seen in figure 2) the algorithm finds all the surfaces having the same CT number as the outer region of bone. A mouse may be used to trace a subsection of a series of images in order to produce an isolated 3D rendering of an object (this technique was used to produce figure 11).

2. Results

As such a huge amount of data has been generated much of it is still in the process of being analysed; hence the results presented here are preliminary in nature.

We found that X-rays were able to penetrate the mummy and casing fairly easily. Most of the time the same X-ray intensity settings as for scanning the lungs of a live patient were required. This is to be expected as the process of mummification involved completely drying out the body, which in life is composed of about 75% water. (To dry the body, the Egyptians covered the body in dry natron (a mixture of sodium carbonate, sodium bicarbonate and sodium chloride) for forty days. Although two people were required to lift the case onto the scanner couch it wasn't as heavy as a live person.

As well as the cross-sectional CT images, the scanner also produces plain X-rays known as topograms or scout films. These are produced to indicate the position of the CT slices. For instance, figure 7 has a number of dotted lines across a side profile image of the head and neck. The numbers on the right hand side of the image indicate the position of each cross-sectional scan. For this project, the plan-view and side-view scout films were taken along the full length of the mummy. In medical terminology, the plan and side view images are called the anterior-posterior (AP) and lateral (LAT) views respectively. Conventionally, left and right are back to front on CT images. This is because the image is displayed as if the body was viewed from the feet.

The CT images show that the brain has been removed, which was often the case. Presumably the Egyptians didn't realise the significance of the brain. Figure 5 shows linen bandages inside the cranium and figure 6 shows a 3D rendering of the linen. Note that the line converges on to the right nasal cavity, indicating that it must have been pushed through into the cranium by this route. From this it follows that the brain was probably extracted through the nose.

Figures 2,3 and 4 show that Jeni has artificial eyes which appear to be in two sections (figure 4). The 3D rendering of the mummified soft tissue of the face shows a form of mask or shroud passing across the eyes keeping them in place. The mummified tissue is more radio-opaque than live tissue – which is to be expected since it is dried out and also the embalmer has applied various resins to the skin. Note that the ears are very well preserved. The face appears to be slightly elongated due to linen stuffed into the mouth.

Jeni's teeth are in remarkably good condition – only one of the teeth is damaged (figure 8). The diet of the ancient Egyptians was contaminated with sand which led to rapid attrition of the teeth – often right down to the pulp. The fact that Jeni's teeth are in good condition suggests that she is not very old. Notice that the upper wisdom teeth (the back molars) seem

slightly lower than the adjacent molars which may or may not have a bearing on Jeni's age. At some point we hope to assess the shape of the molars as these can be an indication of age.

The topograms (figure 9) show a number of amulets. On the CT images these appear as bright areas with black streaks radiating from the object indicating the presence of metal, although the type of metal cannot be determined. Several amulets are evident – around the front part of the neck, a hawk across the sternum (the beak and talons can just be made out); some sort of tag underneath the left arm; a small figure in the region of the naval; a plate over the left abdominal flank; something over the vagina and a scarab over the feet.

In figure 9 a plate is seen covering a hole in the left flank of the abdomen. This hole was used by the embalmer to remove the liver, stomach, lungs and intestines – the heart and kidneys were usually left in place. In the 21st dynasty, the four organs that were removed were mummified, wrapped in linen bandages and placed back inside the body. Our images show that the organ packs have been placed in the chest, whereas the abdomen has been filled with natural fibre packing material.

To date we have not been able to identify any particular organ. Figure 10 shows a section through the organ packs including a curious horseshoe shaped object enclosing a smaller object. Figure 11 shows a 3D rendering of this object, the view is looking in through the opening of the horseshoe, the enclosed object (grey) can just be seen inside. We have no idea what this could be. The joints appear to be in good condition again suggesting a younger person.

3. Conclusion

Although all of the data has not yet been analysed, this study has shown that CT examinations are very effective in the non-destructive examination of mummies. In the future, other mummies in the BM collection may be examined using CT.

4. References

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6. Cockburn A, Barraco R A, Reyman T A and Peck W h. Autopsy of an ancient Egyptian mummy. Science 187; 1155-60, 1975.

Figure 1 - Mummy on the CT scanner

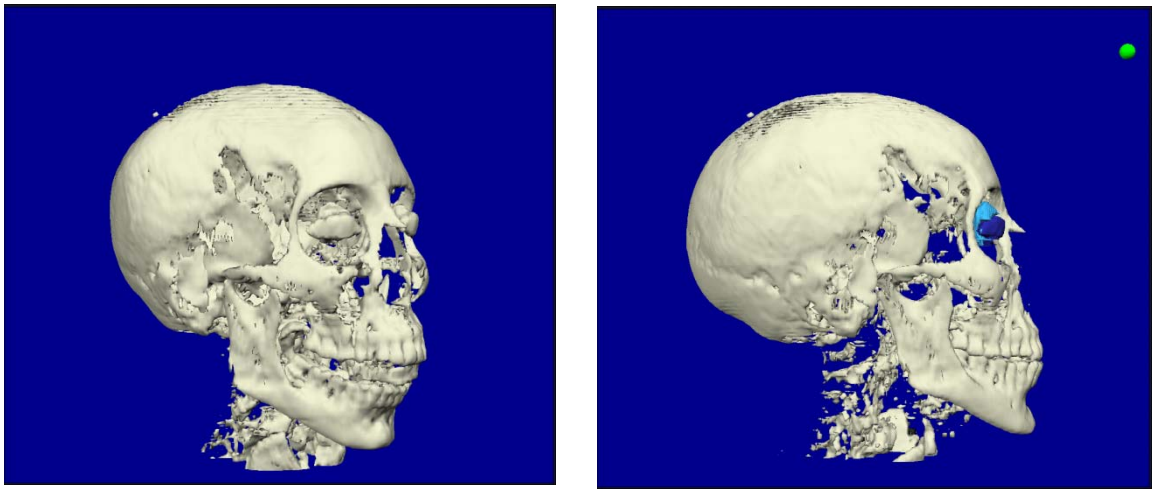

Figure 2 – Oblique frontal and LAT views of the reconstructed bone of the head. The teeth are slightly apart because of linen stuffed into the mouth – some of which may just be seen on the oblique frontal view. The mouth has been closed for the LAT view

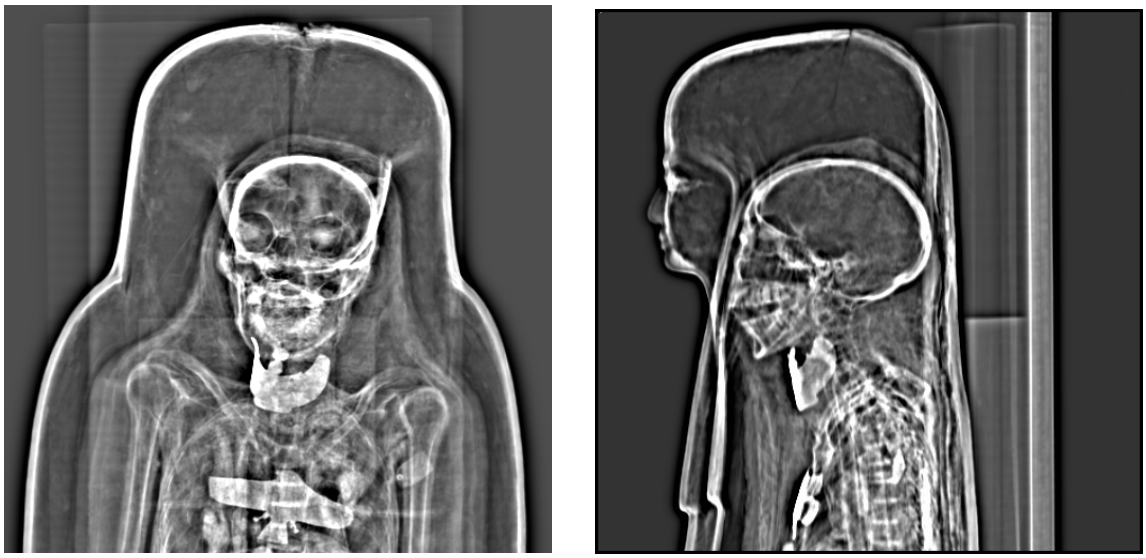

Figure 3 – AP and LAT topograms of the upper portion of the mummy. The position of Jeni's head relative to the head on the case is clearly seen. Note the radio-dense artificial eyes. There is an amulet around the front of the neck and some kind of tag under the left arm. A hawk amulet lies across the sternum – its beak and talons can just be seen. Note also the crack at the top of the case. YThe wrappings across the top of the head could be seen when a torch was shone through the crack

Figure 4 – CT scan through the head. Note the artificial eyes

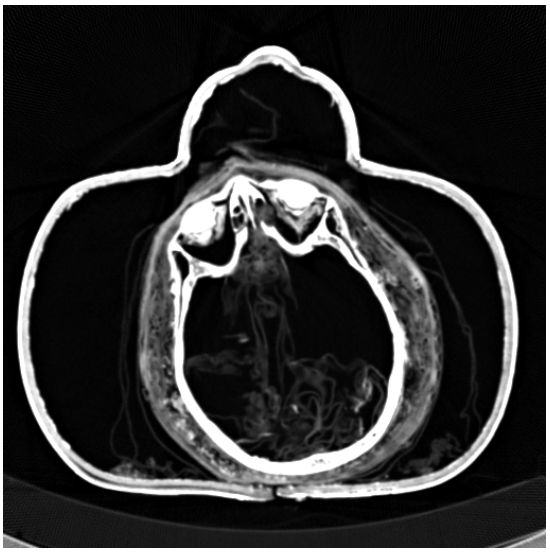

Figure 5 – CT through the head showing linen bandages inside the cranium. The contrast has been adjusted to enable the linen to be seen more easily at the expense of good visibility of the bone

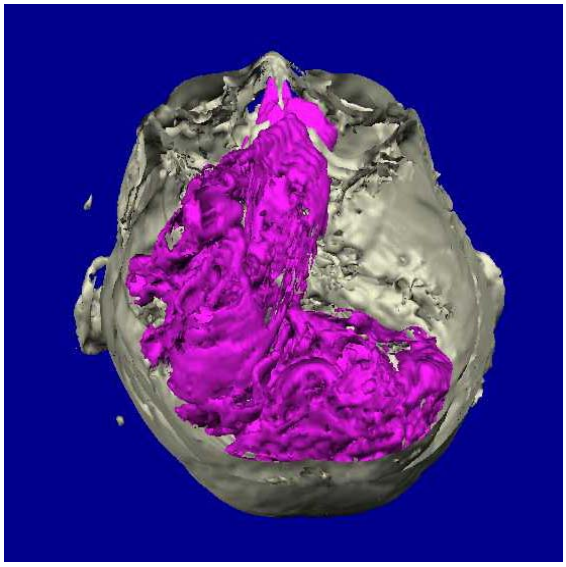

Figure 6 – A 3D reconstruction of the linen inside the cranium, note the convergence towards the right nasal sinus indicating the route through which the brain was extracted

Figure 7 – Topogram of the teeth

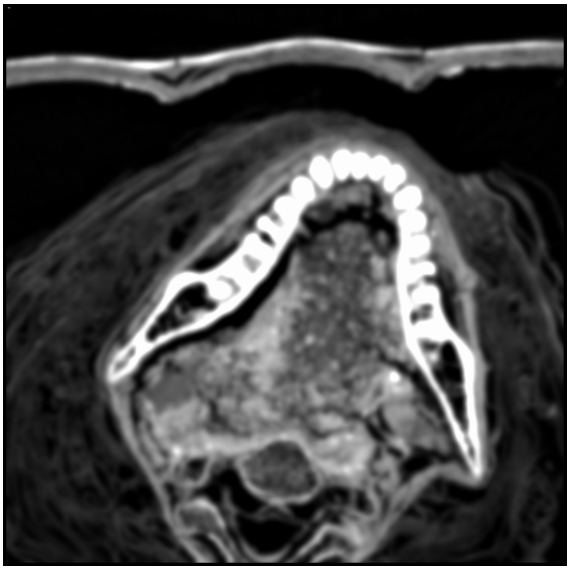

Figure 8 – CT through the teeth

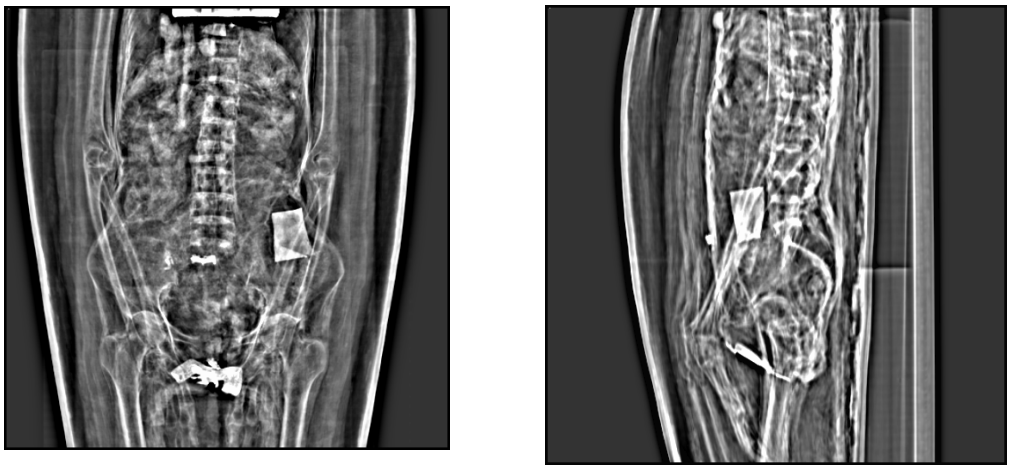

Figure 9 – AP and LAT topograms of the middle portion of the mummy

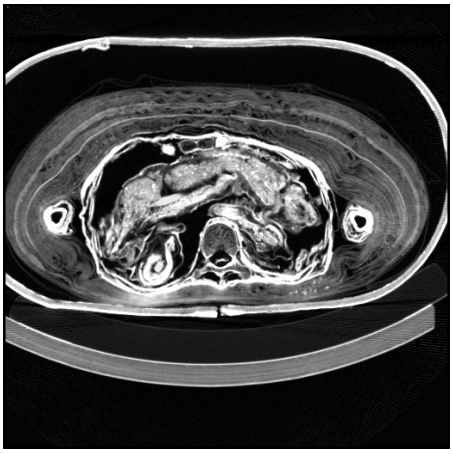

Figure 10 – CT through the abdomen showing the organ packs. In the 21st dynasty, the lungs, stomach, liver and intestines were taken out, mummified, and put back into the chest and abdomen. Note the horseshoe shaped structure on the lower left which appears to be enclosing a smaller object

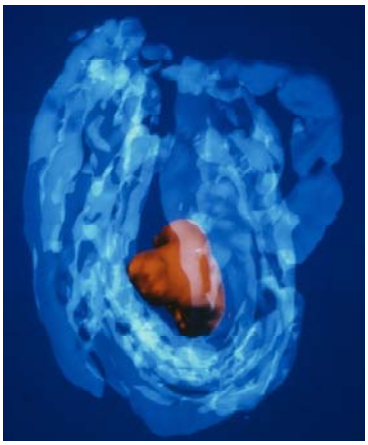

Figure 11 – A 3D rendering of the horseshoe object shown in cross-section in figure 10. The object is about 6 cm tall and 2 cm in diameter. The inner object (in grey) can just be seen inside the opening of the 'horseshoe'. At the moment we have no idea what this might be